STEP VOLTAGE REGULATOR

INTRODUCTION:

The increasing use of motor operated household and farm equipment and the large number of industrial power applications are causing rural power systems more and more concern with voltage regulation problems. Where only incandescent lighting loads are served, these voltage problems are not of major importance for, although a 10% voltage drop reduces the lumen output by about 30%, continued low voltage can be tolerated without damaging effects. On the other hand, with flourescent lamps and motor operated equipment, correct voltage is of prime importance. Flourescent lamps have a definite minimum voltage below which they will not operate, and motors may either refuse to start or if they do start and are allowed to run with low applied voltage will overheat and eventually burn out.

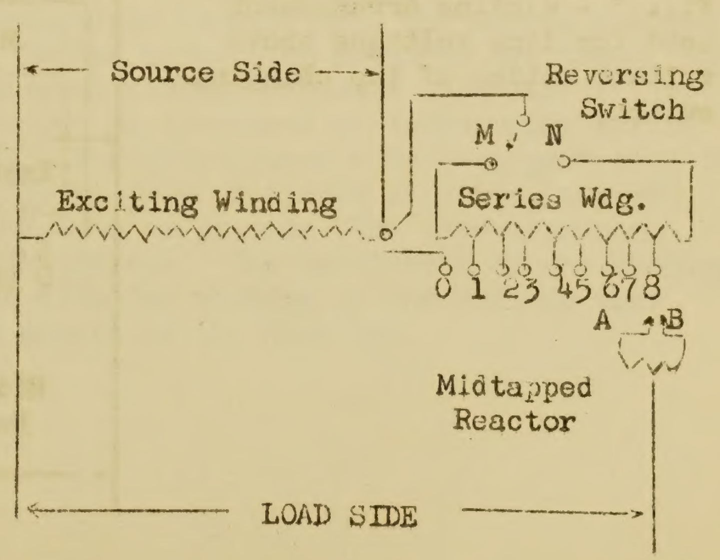
In general, the voltage supplied to consumers may vary either because of fluctuations on the wholesale power supply system, or because of the impedance drop under varying loads on the rural distribution lines. A combination of the two variables naturally results in poor voltage regulation. While voltage variations caused by impedance drops in the distribution lines may be decreased by increasing the wire size, poor voltage characteristics resulting from either of the previously mentioned causes may be corrected by applying voltage regulators. The particular corrective measure employed should be determined by the economic and technical aspects of each individual case; installation of regulators has, in general, been found to be more economical than replacing the conductor. However, this statement is not intended to imply that regulators should be incorporated in the original line design in lieu of larger conductors. (Although various types of regulators are available, this paper deals only with the step regulator.)

GENERAL:

DESCRIPTION AND CHARACTERISTICS

Step type, sometimes called transformer type, regulators are basically auto transformers provided with taps in a series element so arranged that the ratio of transformation can be changed under load. Figure 1 shows such a device with a reversing switch and tap arrangement which provides 16 steps buck and 16 steps boost.

Fig. 1 - Schematic Diagram of Single-Phase Regulator.



The taps are usually arranged in circular form with tap 8 and tap 0 adjacent so that the contactors A and B may revolve in one direction when raising the voltage, and in the other direction when decreasing it. A limiting device, consisting of a center tapped coil, is used with the contactors to provide an intermediate step and to prevent excessive arcing which damages the contacts while tap changes are being made.

It is sometimes necessary to regulate voltages on systems having either currents or voltages above the rating of a tap changing mechanism. For such applications additional windings are incorporated in the regulators as shown in Figures 2 and 3. These windings are, in effect, exciting transformers provided with taps feeding into a series transformer.

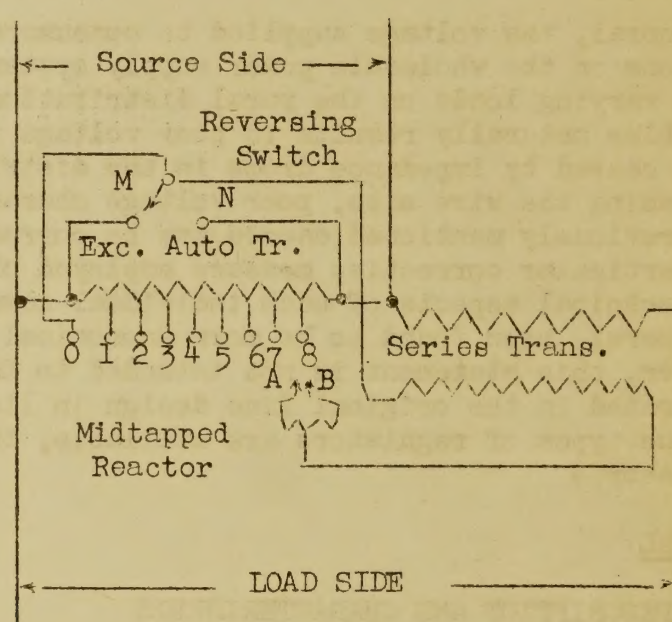


Fig. 2 - Winding Arrangement when Series Transformer is used to reduce current handled by tap changing mechanism.

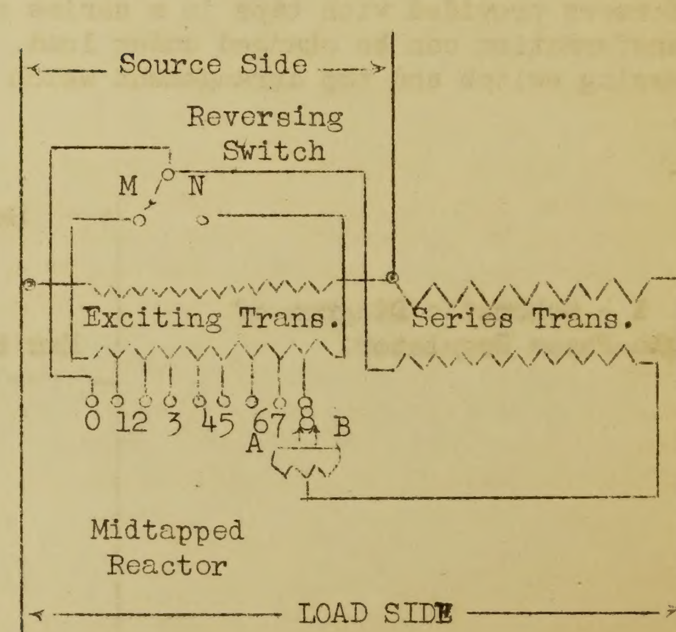


Fig. 3 - Winding Arrangement used for line voltages above voltage rating of tap changing switch.

ASSOCIATED EQUIPMENT

The motor or magnetic device which operates the tap changing mechanism is controlled by a contact making volt meter. The contacts of this volt meter are adjustable so that the band width of the regulator may be set to any desired value. When the voltage on the load side of the regulator rises above or falls below the predetermined band width, the volt meter closes whichever motor circuit provides the direction of rotation required to correct the voltage.

In order that the regulator will operate only when a tap change is really necessary, a time delay is interposed between closing of the contact making volt meter and the starting of the tap changing operating motor. This delay may be set at any value from 5 to 60 seconds and should be sufficiently long to indicate that the voltage change is not momentary.

Through the use of a line drop compensator, the regulator may be set to maintain normal voltage at a distant point on the feeder. The compensator accomplishes this by lowering the voltage applied to the contact making volt meter by an amount proportional to the impedance drop of the line between the regulator and the distant point.

ADVANTAGES

Because of the type of construction and the auxiliary equipment which may be used with it, the step regulator has certain advantages which should be mentioned. The losses in a step regulator are slightly greater than those of a distribution transformer of the same KVA rating but are lower than those of an equivalent induction type regulator. In fact, the exciting current is sometimes as low as one-third of that of the induction regulator. The simple transformer type construction of the step regulator provides high impulse strength and almost trouble free operation. Although the voltage steps of certain classes of step regulators are quite large, step regulators are available which have steps as low as 5/8%. These small steps are about as small as are obtainable even with an induction regulator because of slight overshooting and other operating factors.

PROTECTION

As in all devices utilizing auto-transformer connections, the series winding is connected directly in the line. Unless preventive measures are taken, this winding will be subjected to all abnormal voltage stresses incident to lightning. Furthermore, these stresses might be increased by transformer action and be imposed on the common winding. For this reason a by-pass protector is placed across the series winding. The by-pass protector will not, however, protect against voltage stresses from line to ground; line type lightning arresters should be provided for this purpose. The insulation of the bushings of the step regulator is coordinated with the winding of the unit so that bushings will flashover and prevent damage to the windings.

CLASSIFICATIONS

Step regulators may be classified as feeder, branch feeder, and branch feeder booster based on the number of steps and the range of regulation available.

Feeder regulators are generally considered as those having either 16 or 32 steps between the range of 10% buck and 10% boost; this arrangement provides voltage steps of $1\frac{1}{4}$% or 5/8%, respectively. The tap arrangement for a regulator of this class is shown in Figure 1. These devices are available as single or three phase units. Some types are designed to be mounted on platforms while others may be mounted directly on poles in a manner similar to distribution transformers.

The permissible deviation from a fixed voltage is the factor which governs the number of steps used. Although a regulator may be set to maintain the voltage within closer limits, in practice a rule often used is that the range, or band width, of voltage to be maintained should be at least $1\frac{1}{2}$ times the percent change per step of the regulator. A band width narrower than provided in the above rule is not practical because the number of operations of the regulator will be excessive. If, for example, the voltage on a given system must be maintained within $\pm$ 1% of a given value, either the 16 or the 32 step type will, according to the above rule, operate satisfactorily. However, in the usual case the voltage is subject to sharp but small variations, although its overall trend may be upwards or downwards; in these instances the regulator with the smaller steps will usually operate fewer times.

Although, as previously mentioned, these regulators are available as both single and three phase units, the applications of three phase units on REA lines are somewhat limited. Since most REA loads are single phase, the phase voltages are usually unbalanced to some degree. Because of this unbalance, 3 phase regulators which have a voltmeter in only one line cannot give as satisfactory service as three single phase units which regulate each phase separately. The 3 phase regulator does, however, have an advantage in first cost for it is priced at about 3/4 the price of 3 single phase units.

The second classification, branch feeder regulators, are similar in construction to the feeder regulators but in general have four steps which give up to 10% buck, 10% boost or some combination of buck and boost in $2\frac{1}{2}$% voltage steps (i.e., 0 to 10% buck, 0 to 10% boost, 5% buck to 5% boost, etc.) According to the "$1\frac{1}{2}$ times" rule previously set forth, these devices are suitable when voltage variations of about $\pm$ 2% are of no consequence. This class of regulators are available only as single phase units and are usually pole mounted.

The third classification, branch feeder boosters, are the simplest of the step regulators. The principal difference between these regulators and other classes lies in the number of contact positions and in the tap changing mechanism. The magnetically operated tap changing mechanism provides only two possible contact

positions. The series coil which provides a maximum buck or boost of 10% is usually divided by taps into four sections so that the smallest voltage step is 2½%. The tap connections are arranged so that a fixed buck or boost is provided for normal voltage conditions and an automatic tap change provides additional buck or boost to counteract voltages which are either above or below certain predetermined levels. A number of combinations of buck and boost can be arranged provided the range does not exceed 10% of the supply voltage.

METHOD OF OPERATION

A simple schematic diagram for a single phase feeder regulator is shown in Figure 1. The exciting winding of the transformer is shown connected across the line to be regulated. An automatic, mechanically operated reversing switch M-N is applied so that the series winding will either buck or boost the voltage across the exciting winding.

The series winding is provided with 8 taps which are connected to wide stationary contacts on the tap changing mechanism. Two moving contacts, A and B, which are connected to opposite ends of a midtapped reactor, move as a unit with a snap action from one operating position to the next. The distance between these two contacts is such that in any operating position, the contacts are either both on the same wide stationary contact or one is on each of two adjacent contacts. The width of each of the moving contacts is less than the space between the stationary ones so that no bridging is possible. These positions are shown by the sketch of Figure 4.

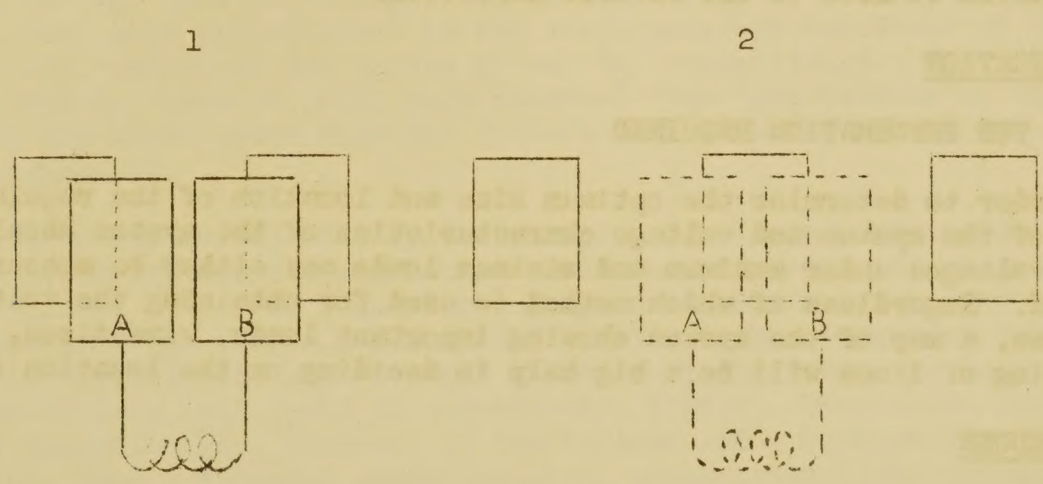


Figure 4

Stationary and Moving Contacts

The double moving contacts, arranged as indicated with the midtapped reactor, not only reduce arcing when taps are changed, but provide voltage steps between that of the taps. Thus with 8 taps in the series coil, 16 operating positions, besides the zero position, are possible for each position of the reversing switch.

The sequence of operations of the tap change is as follows: To change taps from full boost position where contacts A and B are both on stationary contact 8, and the reversing switch is in position M, as shown in Figure 1, to the next lower position, the moving contacts snap to a position where A is on contact 7, but B is still on contact 8. During the instant that A is crossing the gap between contacts 8 and 7, the load current is carried entirely by that part of the transformer winding connected to B; but as soon as A is in contact with 7, the load current again will be divided equally between the two halves of the reactor winding, and the voltage obtained will be that midway between the voltage of contacts 7 and 8, thus providing the intermediate steps.

If the contactor is moved until both contacts A and B are on stationary contact 0, the voltage boost will be reduced to zero, as no part of the tapped series winding is in the circuit. If a lower voltage is required, the reversing switch is moved automatically from M to N while contacts A and B are still on stationary contact 0. As the stationary contacts are arranged in a circle, the next movement will cause contacts A and B to snap into a position such that A is on contact 8, but B is still on contact 0. This is the first buck position, for the reversing switch has reversed the polarity of the series winding causing it to buck rather than boost the voltage of the exciting winding. If necessary, the contactor can be moved over taps 8, 7, 6, etc. until A and B are both on contact 1 which gives the maximum buck or lowest load side voltage.

If the voltage on the load side is to be raised rather than lowered, the contact making volt meter will close the motor circuit which causes the contactor mechanism to move in the reverse direction.

APPLICATION

THE INFORMATION REQUIRED

In order to determine the optimum size and location of the regulator, the loading of the system and voltage characteristics of the system should be known. The voltages under maximum and minimum loads may either be measured or calculated. Regardless of which method is used for obtaining the voltage characteristics, a map of the system showing important loads, wire sizes, and length and phasing of lines will be a big help in deciding on the location of the regulator

PROCEDURE

Since the size of the regulator to be used depends on the load taken from the lines beyond it, the location must be determined before the size can be calculated. The procedure for determining the proper location of the regulator and any associated equipment can best be demonstrated by an example. For this

purpose refer to the assumed system indicated on the top of Figure 5 showing the loading under both the maximum and minimum conditions. The voltages at various points on the system were calculated for both maximum and minimum load conditions; the results are shown graphically on the lower part of Figure 5. An examination of the maximum load voltage characteristics indicates that to provide enough voltage correction to maintain the voltage within 10% of normal, at least two 10% regulators in series are needed.

A number of factors should be considered in deciding on the exact location of the regulators. Some of these are: (1) The maximum voltage at any point on the regulated system should not be high enough to overexcite distribution transformers or burn out lights. There is no general agreement on what the exact maximum allowable value is, but it is probably in the neighborhood of 126 volts on a 120 volt system. (2) The maximum number of members should be served at or near 100% voltage. (3) Important (large power) loads should preferably be on the high, rather than on the low, voltage side of the regulators.

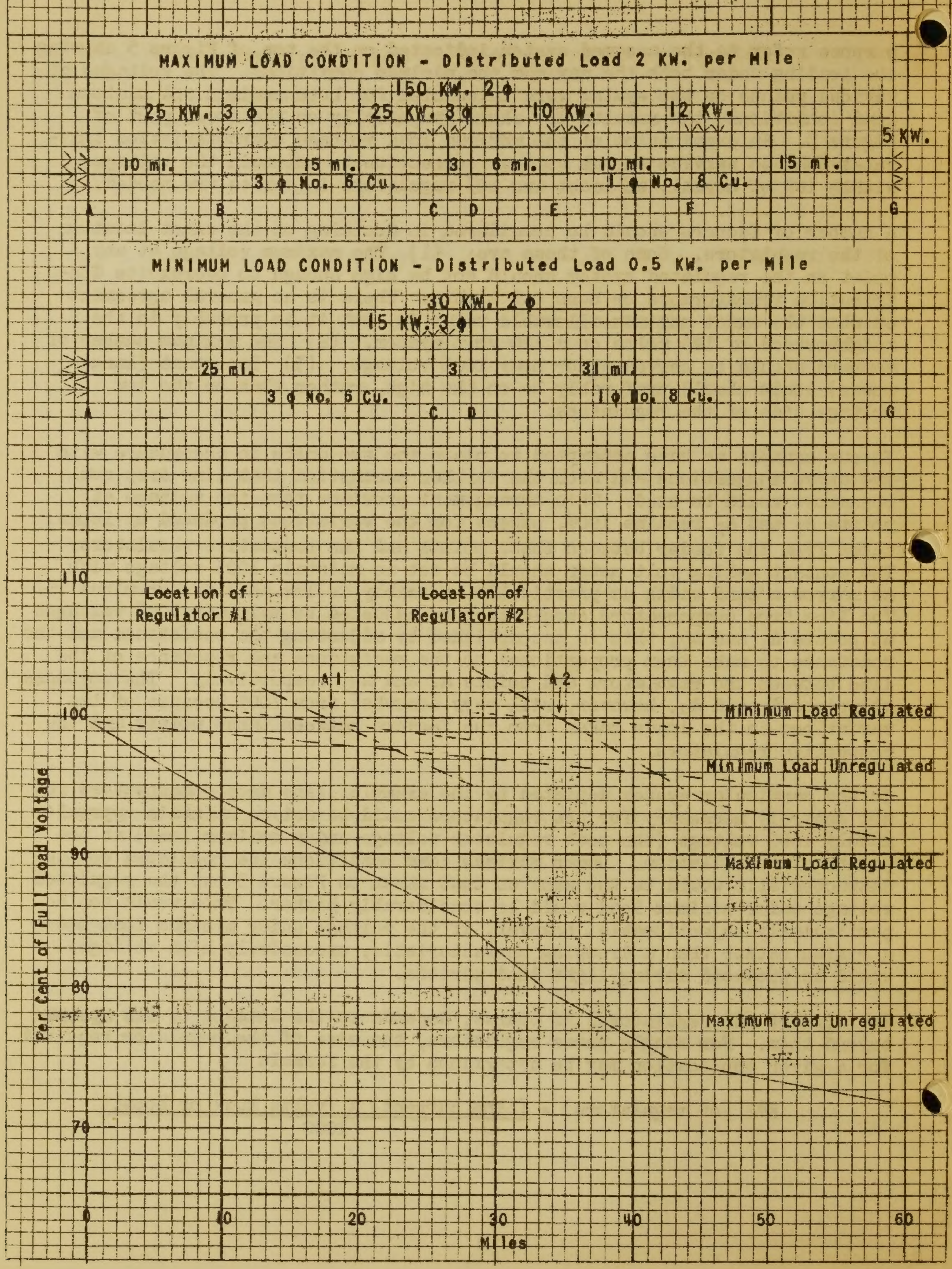
In our example we have attempted to place the two units in accordance with the above suggestions and with the further assumption that line drop compensators would be used. This arrangement provides that the voltage at points A_1 and A_2 remains 100%, except for the variations produced by loads taken from the feeder between these points and the respective regulators. The contact making volt meter should be set to maintain 100% voltage with as narrow a band width as practicable, possibly as low as plus, or minus 1%. The line drop compensators should then be adjusted to maintain 100% voltages at points A_1 and A_2; this is accomplished by adjusting the resistance and the reactance to make them proportional to the resistance and reactance of the line between the regulators and points A_1 and A_2, respectively. The voltages at points A_1 and A_2, however, will vary somewhat from 100% because of the variations in the loads taken from the feeders between these points and the respective regulators.

In the particular system depicted by the example, line drop compensators are not entirely necessary for the regulators could be set to maintain approximately 104% voltage (the peak regulator voltage under maximum load) at the points of installation. Under maximum load conditions the regulated voltage characteristic would be the same as that shown on Figure 5 but the regulated voltage under minimum load would be considerably higher. This would not be particularly objectionable; however, if the voltage under minimum load had a rising rather than a drooping characteristic, excessively high voltages would be produced during light load periods.

The size of the regulators, of course, depends on the loading of the system beyond them. For single phase regulators, the size of the regulator required for a given application may be determined by the formula

$$\text{KVA (of regulators)} = \frac{\text{(Line current) X (volts buck or boost)}}{1000}$$

Fig. 5 Voltage Characteristic Curves



For three phase wye connected regulators, the size is given by

$$\text{KVA (of regulator)} = \frac{3 \text{X} (\text{line current}) \text{ X } (\text{volts buck or boost})}{1000}$$

The line current is measured at the point of installation of the regulator and the volts buck or boost of the regulator is based on the phase to neutral voltage.

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